Physics opportunities with a 2^{nd} focus

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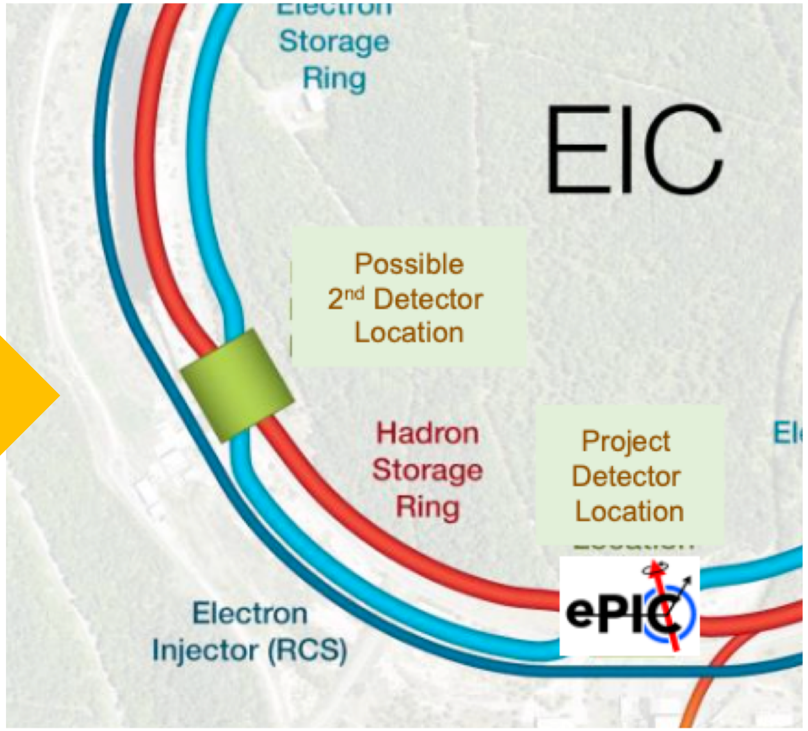
The 2^{nd} detector



EIC UG meeting, Warsaw, Poland, July 30, 2023

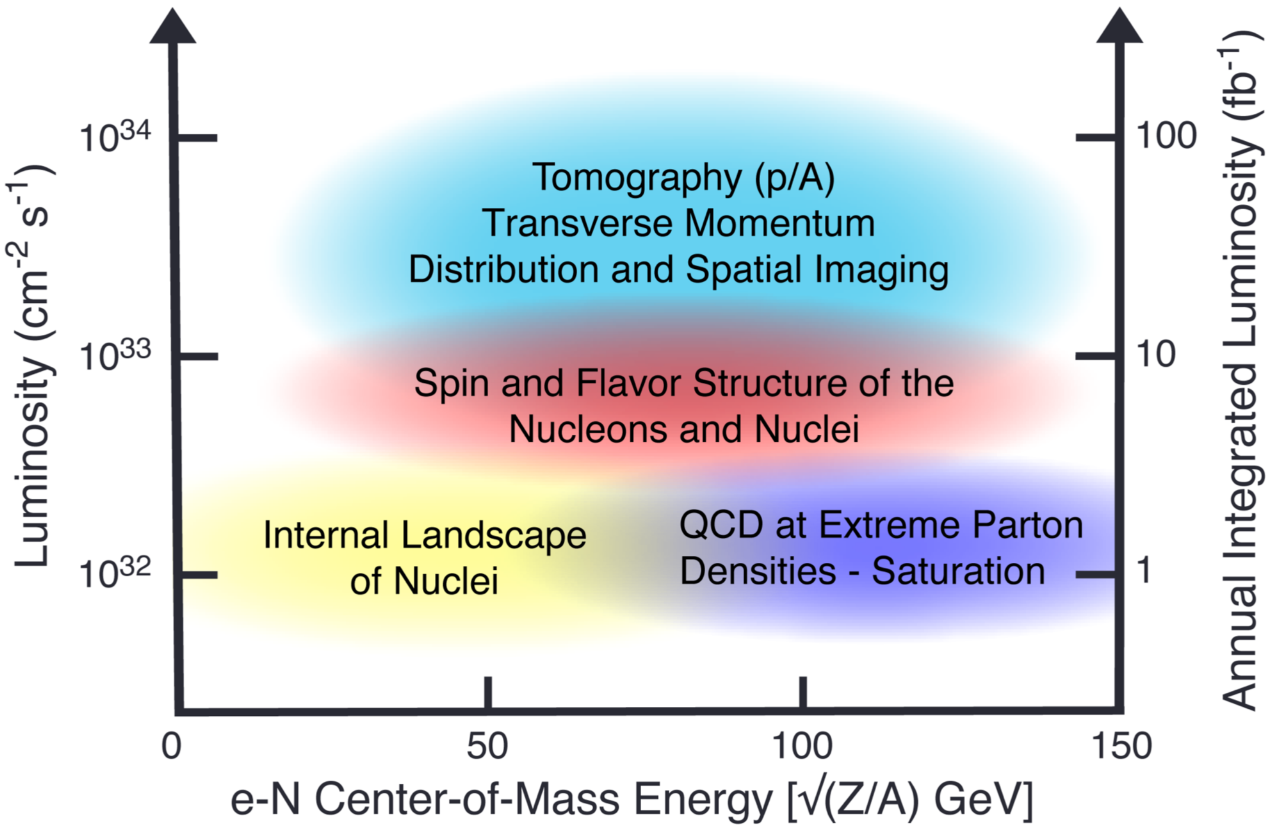
Motivation for a 2nd detector and IR with a 2nd focus

- Needed to unlock the full discovery potential of the EIC
  - Cross checks of key results are essential!
  - Implies a general-purpose collider detector able to support the full EIC program

- New physics opportunities
  - Take advantage of much-improved near-beam hadron detection enabled by a **2nd focus**,
  - Impacts, for instance, **exclusive / diffractive physics**; greatly expands the ability to measure **recoiling nuclei and fragments from nuclear breakup**.
  - New ideas beyond the Yellow Report and CD0 (EW, BSM)? Your input is essential!

- Complementary design features
  - Possible to reduce combined systematics (as for H1 and ZEUS)
  - Particularly important for the EIC where high statistics mean that uncertainties for **a large fraction of the envisioned measurements will be systematics limited**

Luminosities in IR6 (ePIC) and IR8 (Detector 2)



- Tomography and imaging require higher luminosities – but also excellent far forward acceptance
- When the EIC reaches its design luminosity, measurements in these categories will mostly become systematics limited

Forward detection at the EIC is unique due to a numerical coincidence

- At the EIC, the longitudinal momentum loss of the scattered “target” particles is not negligible. In the relevant range of x, it is typically larger than the intrinsic momentum spread of the beam.
  - In DIS, dp/p ~ x (the momentum of the struck parton).
  - The intrinsic momentum spread (1σ) in the beam is typically a few times 10^{-4}.

- For x larger than the (10σ) beam momentum spread we can thus in principle detect *all* scattered particles – even ones emerging at zero degrees ($p_T = 0$).
  - At lower x one cannot reach $p_T = 0$, but the low-p_T acceptance can be greatly improved

- Ions that change their rigidity (A/Z) behave like a proton experiencing a longitudinal momentum loss.
  - A heavy ion losing one nucleon changes its rigidity by ~10^{-2}, which is comparable to the (10σ) beam momentum spread, making it possible to detect (tag) A-1 nuclei

Three strategies for detecting forward-going particles

$$\sigma = \sqrt{\beta\epsilon + \left(D\frac{\Delta p}{p}\right)^2}$$

These are mutually supportive and ideally we want to benefit from all three

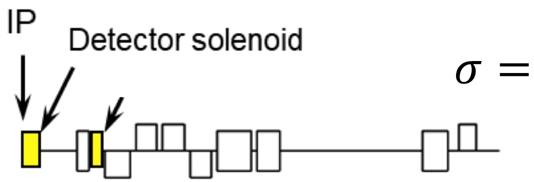
- **Drift**
  - A particle scattered at a small angle will eventually leave the beam (which could be far away).
  - When using *only* this method, the scattering angle has to be larger than the angular spread (divergence) of the beam, which is determined by the strength of the focus at the collision point (β^*).

- **Dispersion** (D) translates a longitudinal momentum loss into a transverse displacement
  - dx = D dp/p , where dx is the transverse displacement at $p_T = 0$
  - With D = 0.4 m, dp/p = 0.01, and $p_T = 0$, the transverse displacement for would be **0.4 cm**

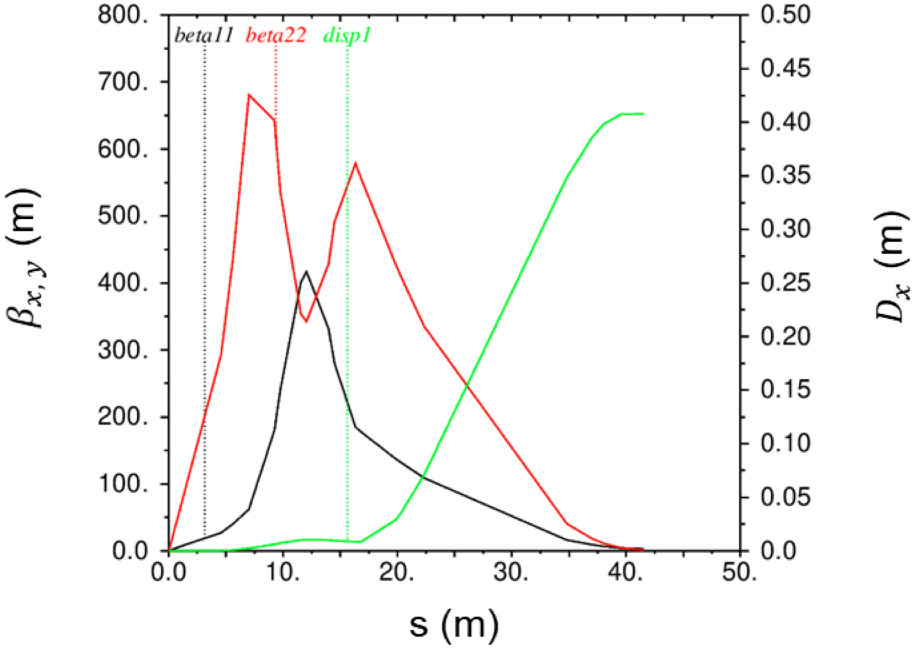
- **A 2nd focus** can reduce the (10σ) beam size at the detection point
  - Enables detectors to be placed closer to the beam – very effective in combination with dispersion
  - Without a 2nd focus (IR6): **4 cm** (high luminosity / divergence), **2 cm** (low luminosity / divergence)
  - With a 2nd focus (IR8): **0.2 cm** (high luminosity / divergence)

Beam optics and the actual trajectory of a $p_T = 0$ particle (blue)

- For optimal detection, the (2nd) focus has to coincide in x and y at the point of maximum dispersion (green line).
  - σ_x and σ_y should be comparable at the 2nd focus (and thus $\beta_x < \beta_y$ since $\varepsilon_x > \varepsilon_y$)

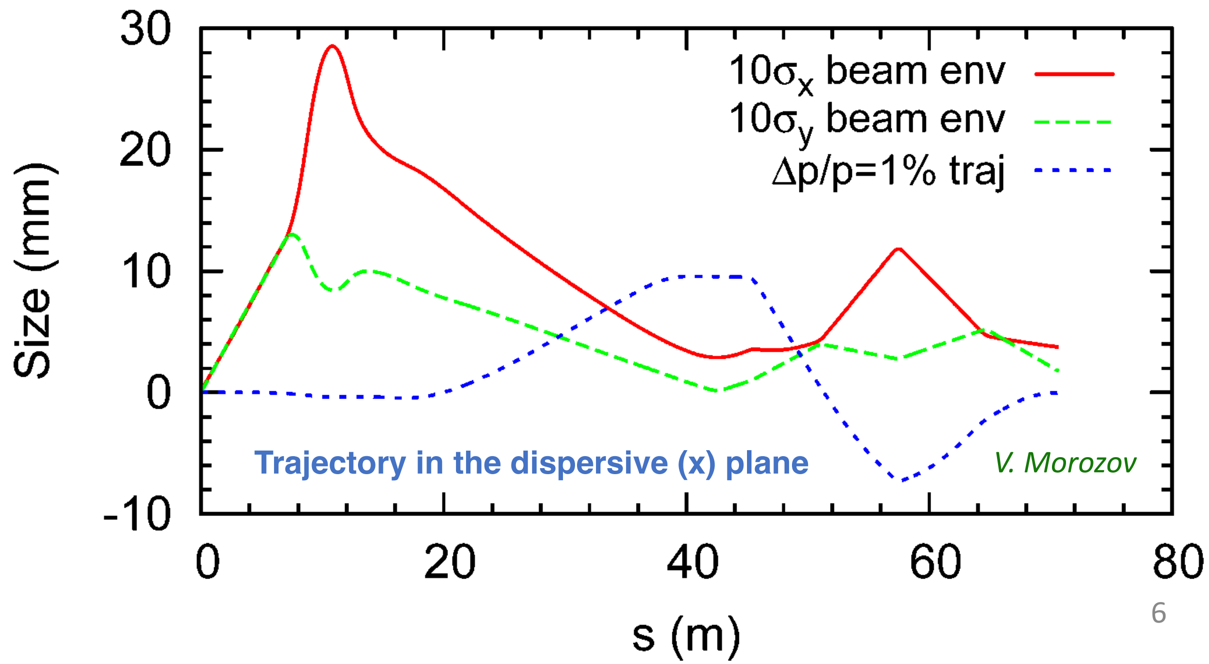


$$\sigma = \sqrt{\beta\epsilon + \left(D\,\frac{\Delta p}{p}\right)^2}$$



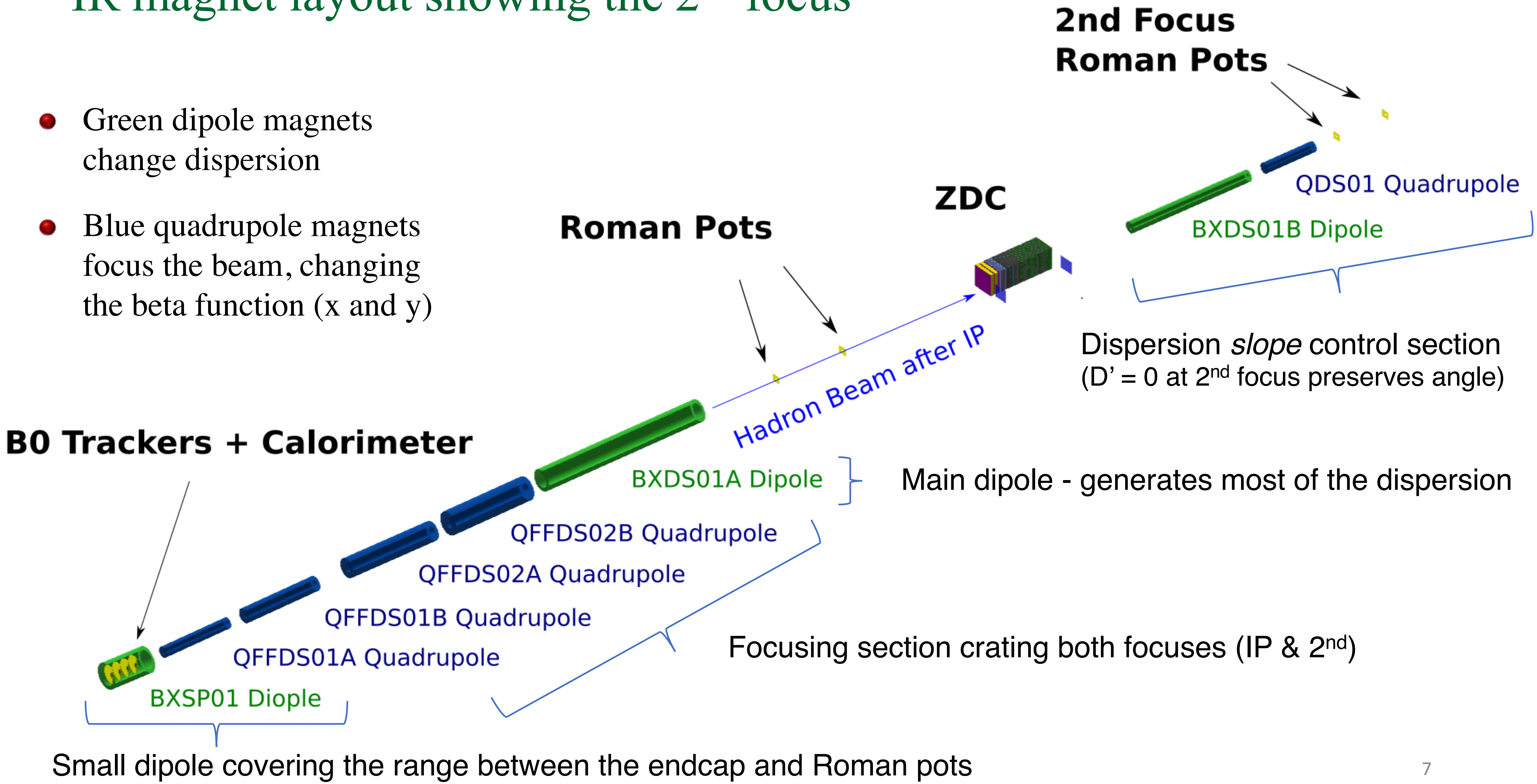
- A zero degree particle (blue) briefly emerges from the beam at the 2nd focus about 40 m downstream of the IP where it can be detected
  - Particles with a non-zero angle emerge earlier .

- The 2nd focus refers to the *beam*. Scattered particles have their *maximum* transverse displacement here.



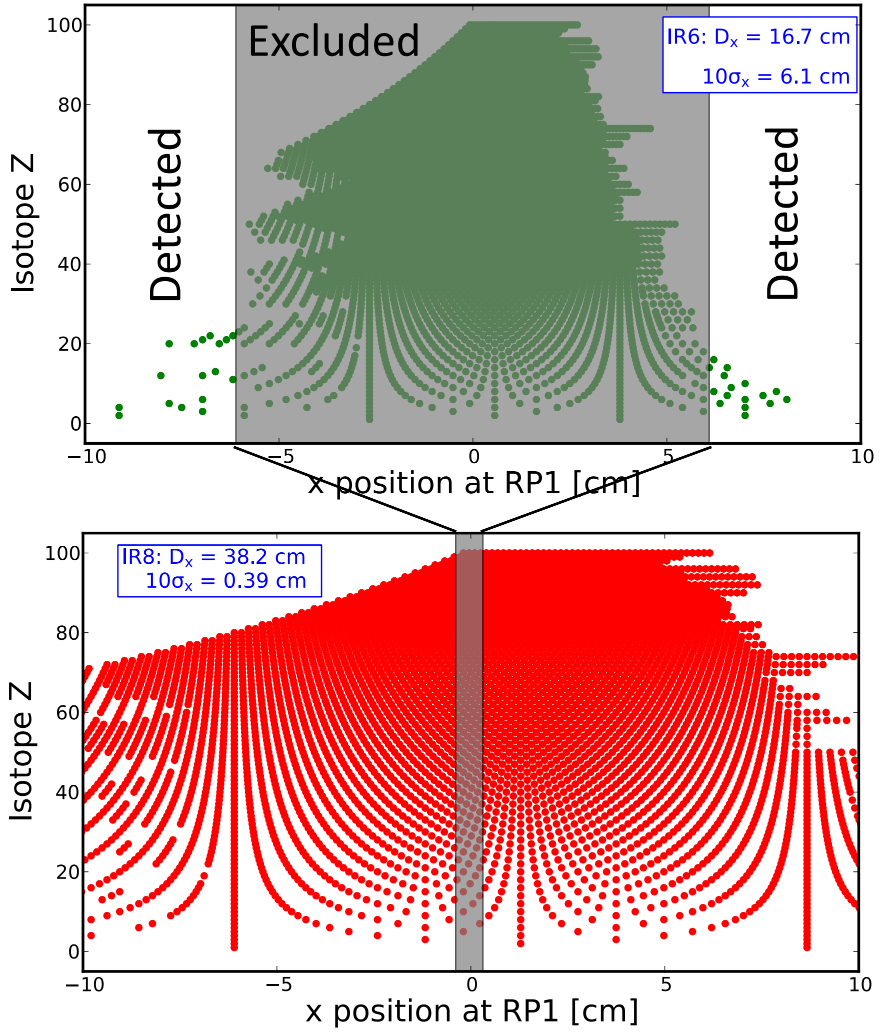
IR magnet layout showing the 2^{nd} focus

- Green dipole magnets change dispersion
- Blue quadrupole magnets focus the beam, changing the beta function (x and y)



EIC far-forward acceptance with and without a 2nd focus

Ion fragments from ^{238}U



x position ~ A/Z

Without 2nd focus:
(EPIC @IR6)

← Z' vs x_{RP}

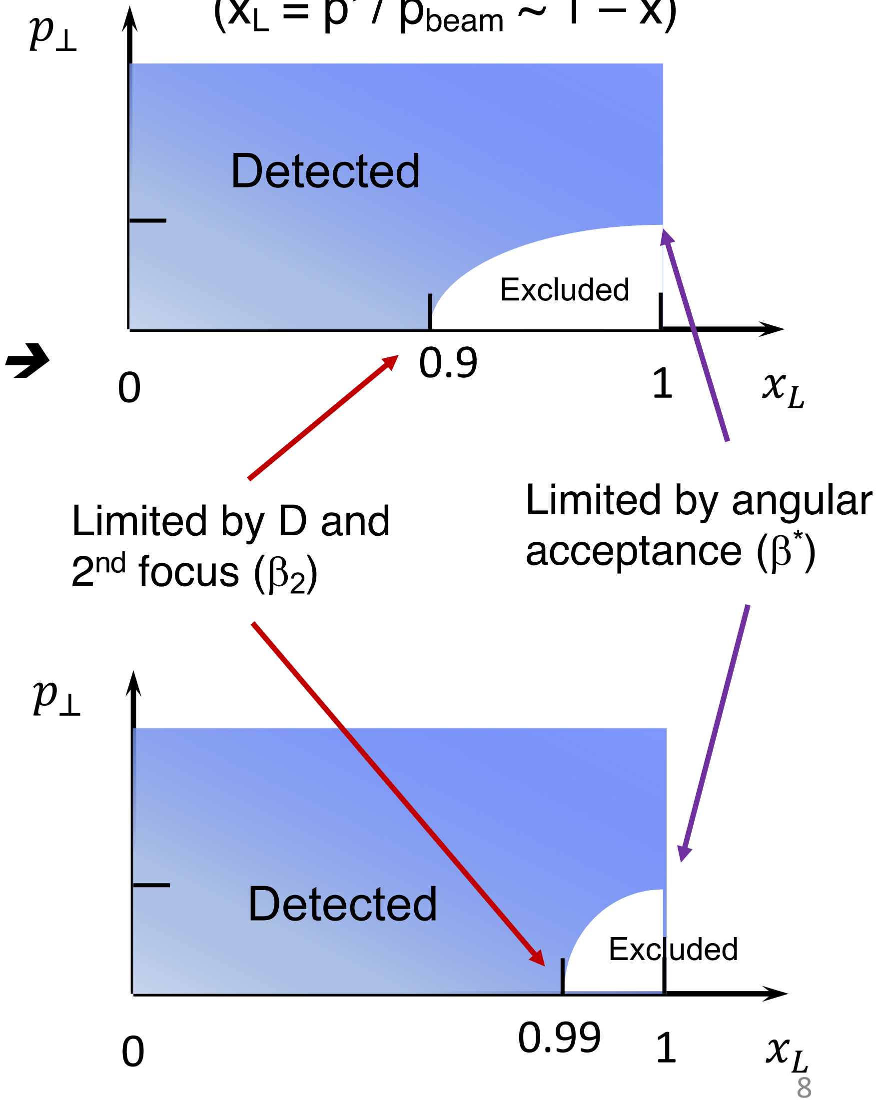
$p_\perp$ vs x_L →

With 2nd focus:
(Detector 2 @ IR8)

Order-of-magnitude improvement in forward acceptance

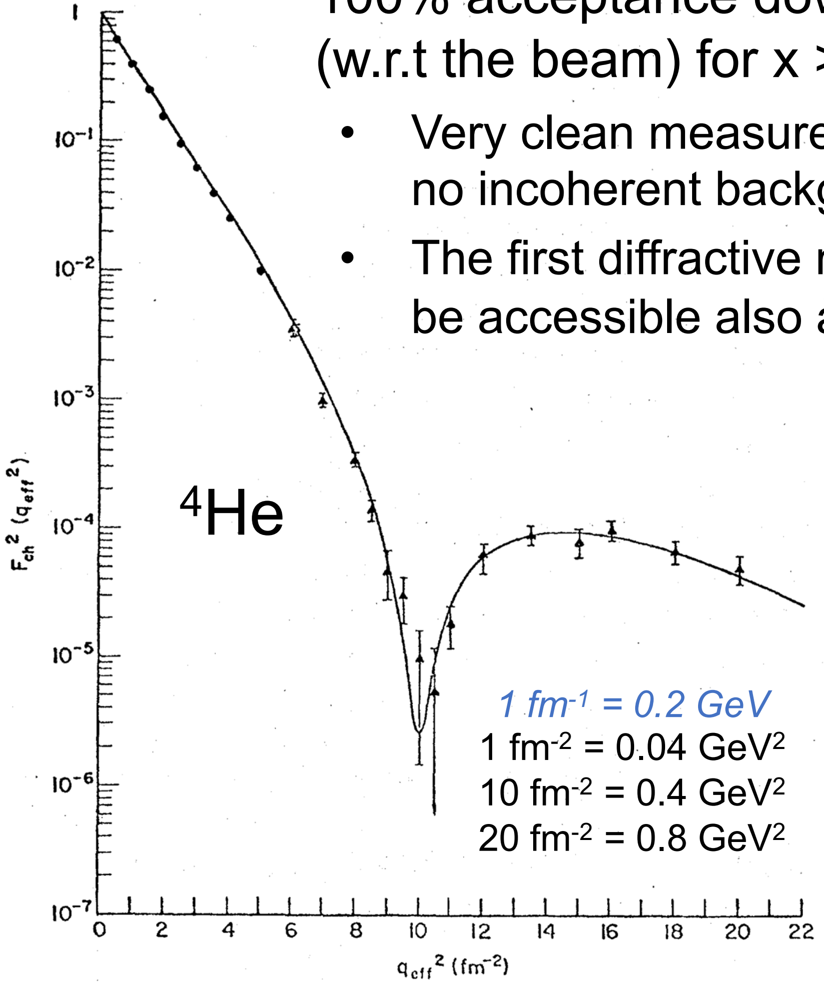
Exclusive protons

($x_L = p' / p_{beam} \sim 1 - x$)

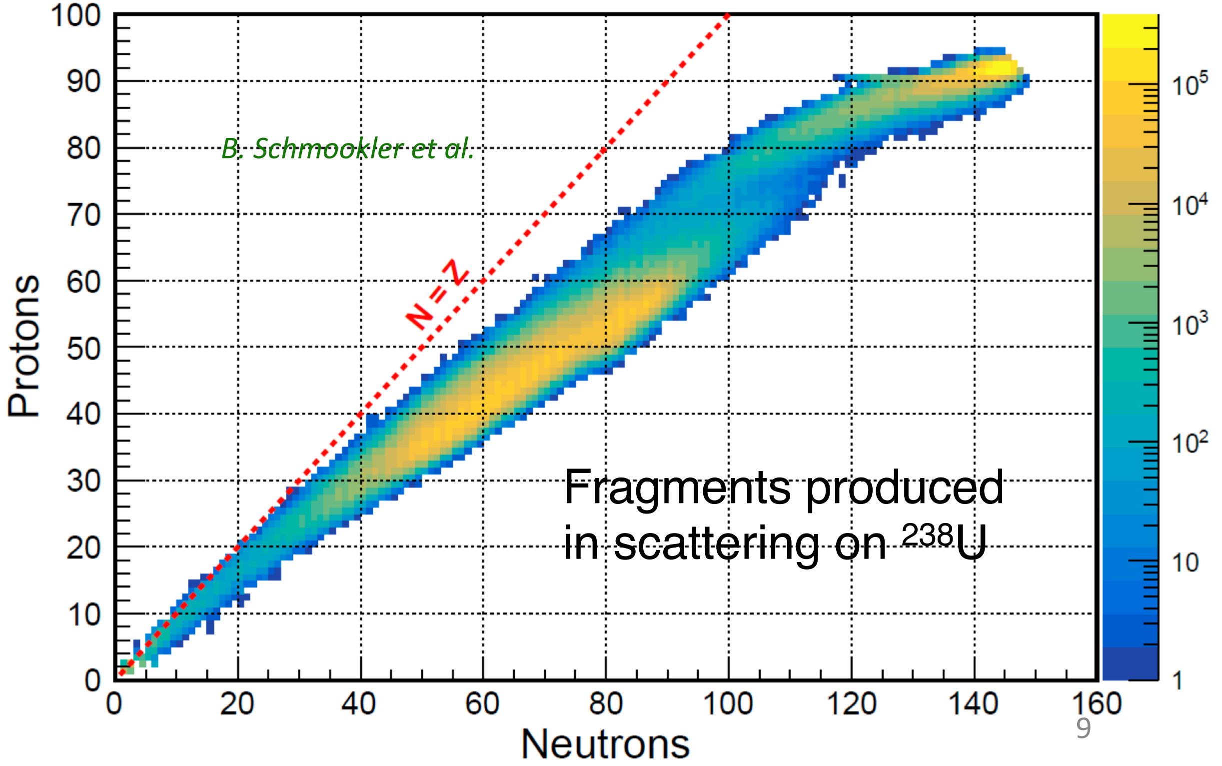


Example: exclusive coherent scattering on nuclei

- For light nuclei, the 2nd focus enables *detection* with essentially 100% acceptance down to $p_T = 0$ (w.r.t the beam) for $x > 0.01A$.
  - Very clean measurement with no incoherent background
  - The first diffractive minimum will be accessible also at low x.

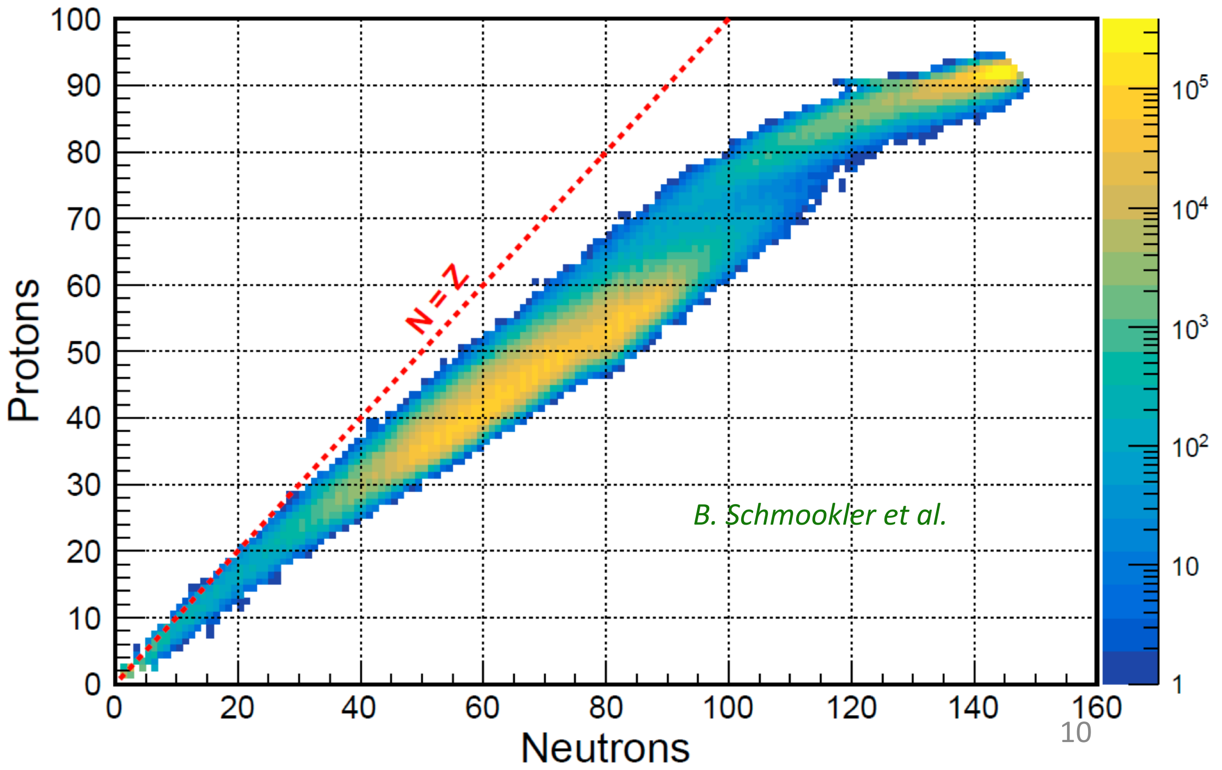


- For heavier nuclei, incoherent events can be suppressed by detecting fragments (including neutrons and photons) from the breakup.
  - Fragments are particularly important for the high-t tail



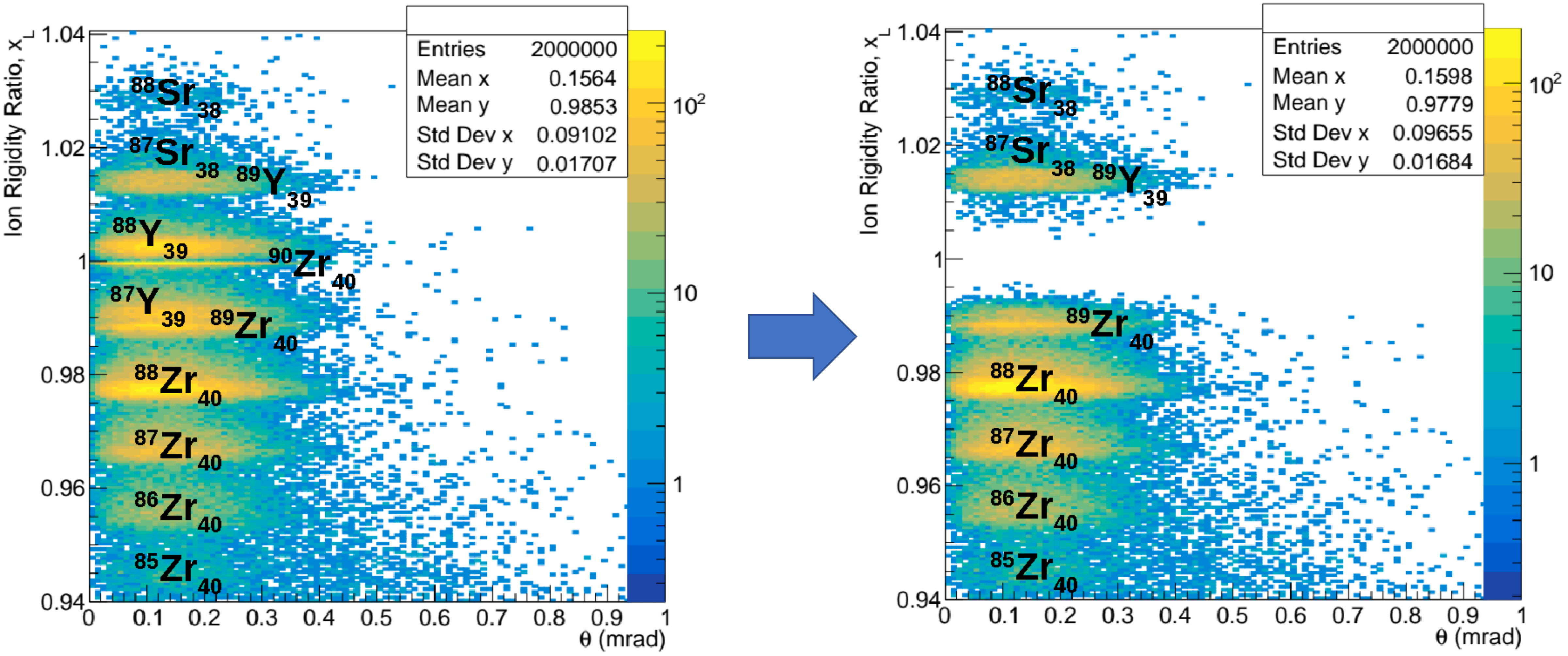
Example: tagging of heavy spectators

- Both IR6 and IR8 support tagging of spectator protons from light ions (d, He)
  - These spectators have magnetic rigidities that are very different from that of the beam ions
- A 2nd focus will allow tagging of heavy spectators
  - A-1 nuclei up to Zr-90
  - A-2, *etc*, for almost any nucleus
- Tagging of heavy spectators enables, for instance, measurements of reactions on a bound nucleon
- The produced fragments will also contain rare isotopes.
  - Gamma spectroscopy possible by measuring boosted forward-going photons in coincidence
  - Interest from the FRIB community



Example: A-1 tagging with 2nd focus using a ^{90}Zr beam

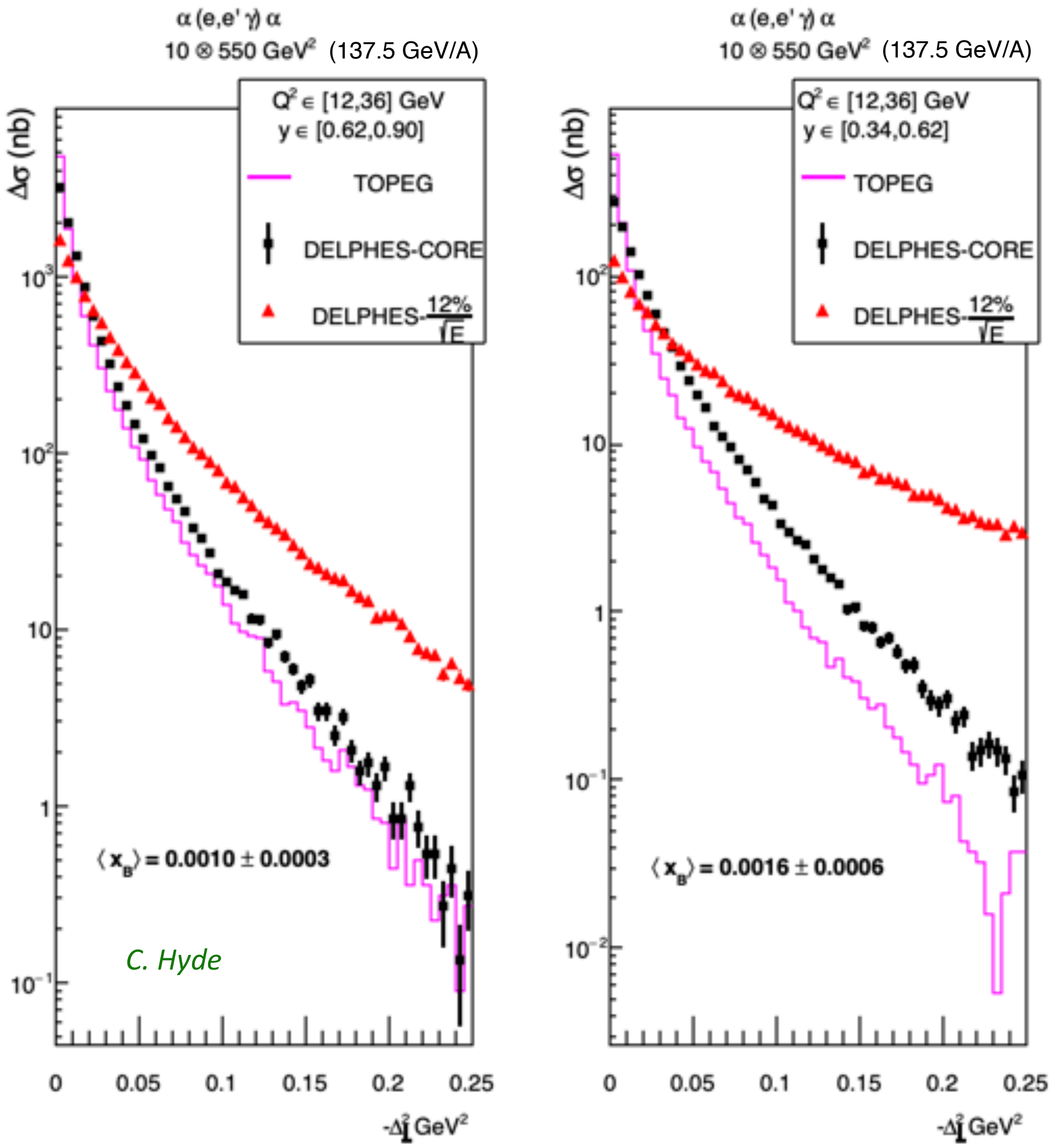
arxiv:2208.14575



generated (BeAGLE)

detected (Geant)

Example of detector synergies: reconstruction of Δ_{perp} using the DVCS photon

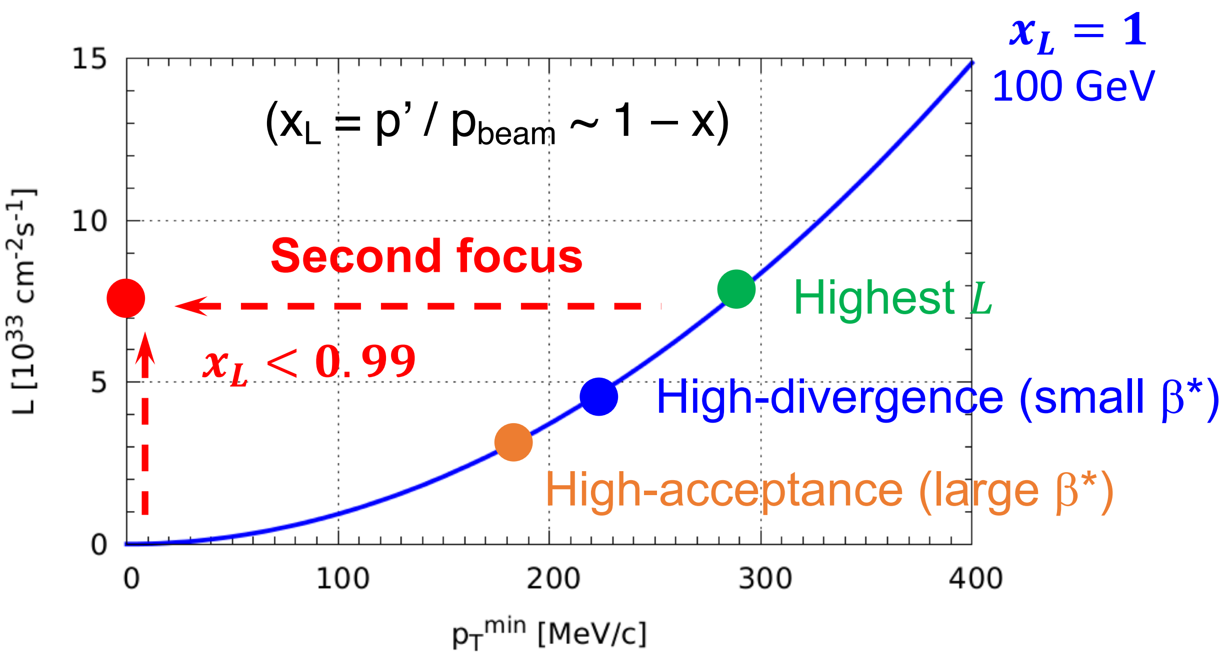


- With a 2nd focus, light ions from coherent processes can be *detected* down to $p_T = 0$ (w.r.t. the beam)
- For heavier ions (*e.g.*, ^{12}C to ^{90}Zr), the recoiling ion cannot be detected, but the excellent acceptance for ion fragment makes it possible to provide a clean breakup veto to ensure exclusivity.
- For heavy ions, the only way to reconstruct Δ_{perp} (essentially p_T w.r.t the virtual photon) is to use the scattered electron and DVCS photon
  - This method is also very helpful for lighter nuclei
- The study on the left shows the importance of the photon energy resolution of the barrel EMcal
  - CORE (black) used $PbWO_4$ with 1-2% resolution
  - ePIC's GlueX-like EMcal would fall in-between the $PbWO_4$ (black) and 12% (red) points.

Thank you!

Luminosities in IR6 (ePIC) and IR8 (Detector 2)

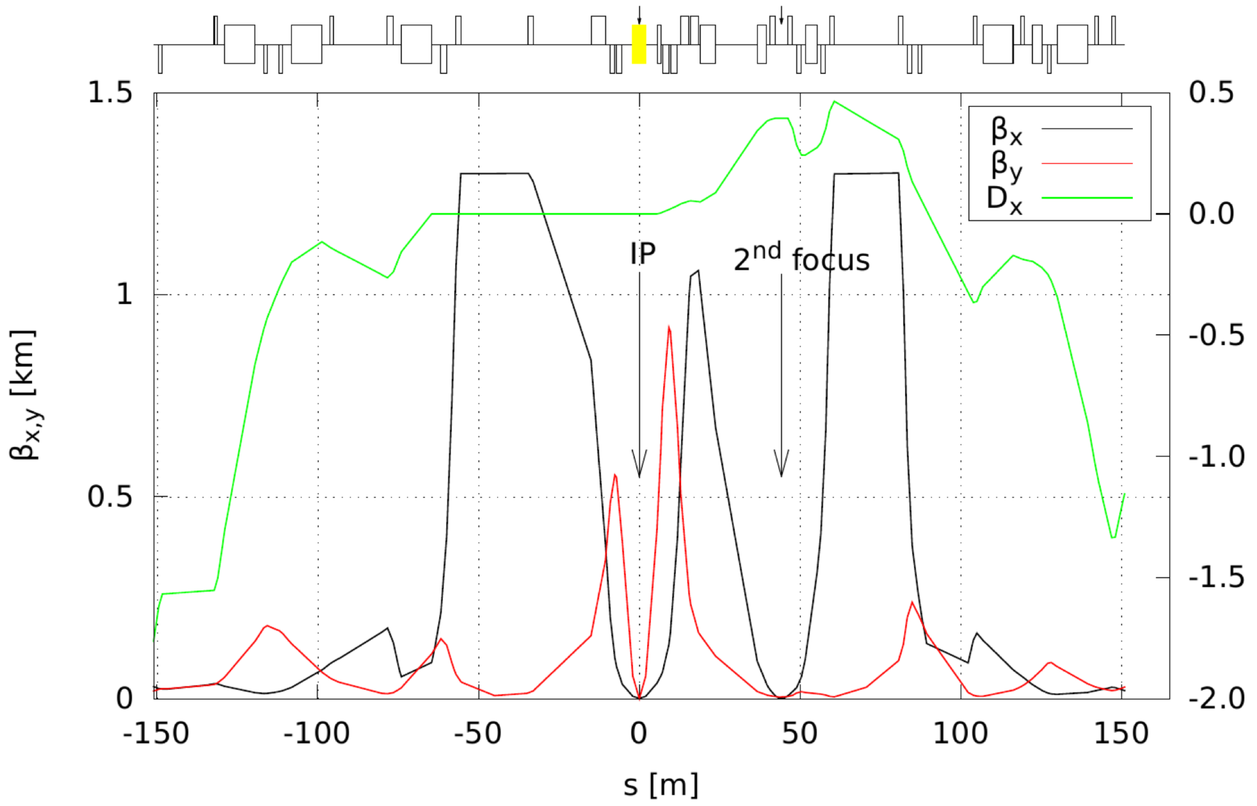
18x275	10x275	5x275	10x100	5x100	5x41
1.65×10^{33}	10.05×10^{33}	5.29×10^{33}	4.35×10^{33}	3.16×10^{33}	0.44×10^{33}

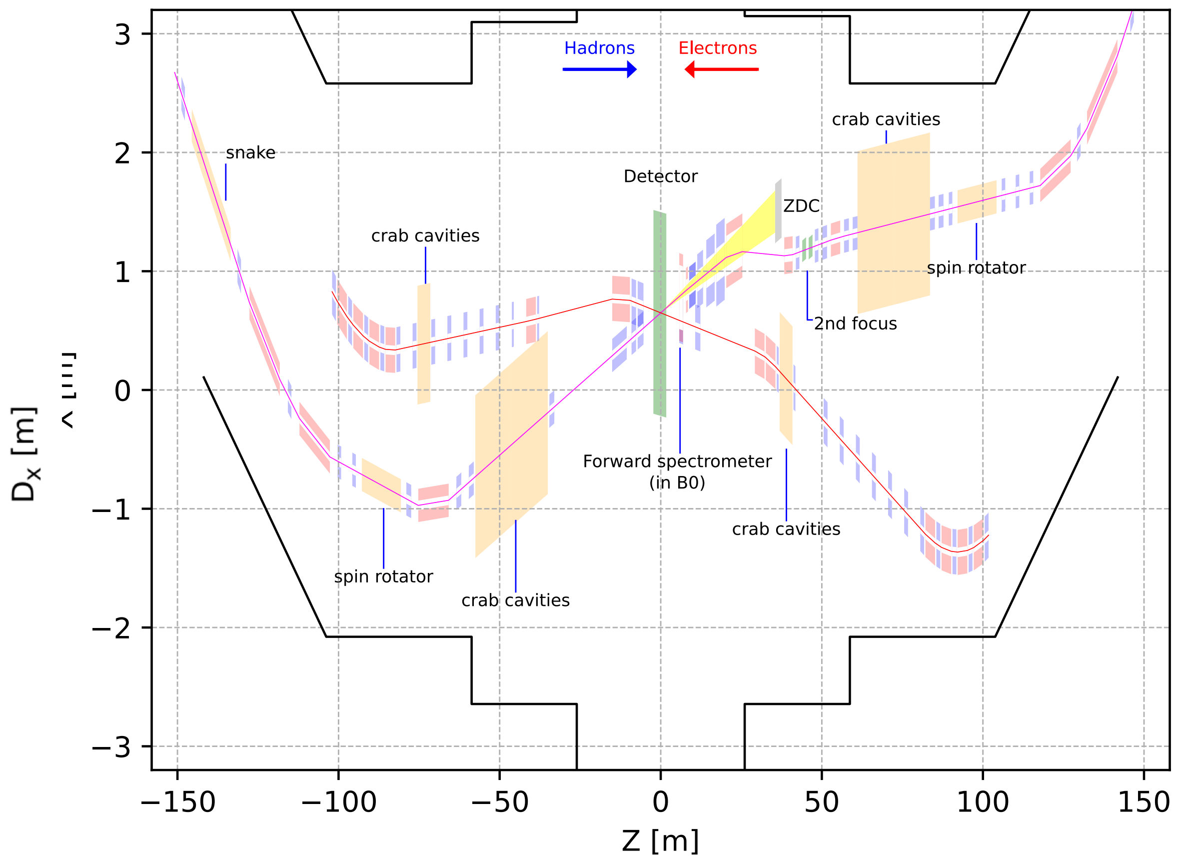


- The maximum luminosity will be similar for both Detector 1 and 2.
- When operated together, they will share the *beam current* (*luminosities* can be different).
- In IR6, a higher luminosity reduces the forward low-p_T acceptance.
- Due to the 2nd focus, IR8 can operate at max luminosity without any acceptance penalty for x > 0.01, and a smaller one at lower x

This complementarity will allow for a global optimization. Detector 2 will have a natural advantage for exclusive / diffractive physics, and in particular for detection of nuclei.

Crossing angle





- The crossing angle has little impact on forward detection and is unrelated to the 2nd focus. The current value (35 mrad) is driven by the space needed for the crab cavities
  - A larger crossing angle is helpful for beamline separation n IR8 since the B0 dipole is inbending
  - A 2nd focus would work equally well with a 25 mrad crossing angle.